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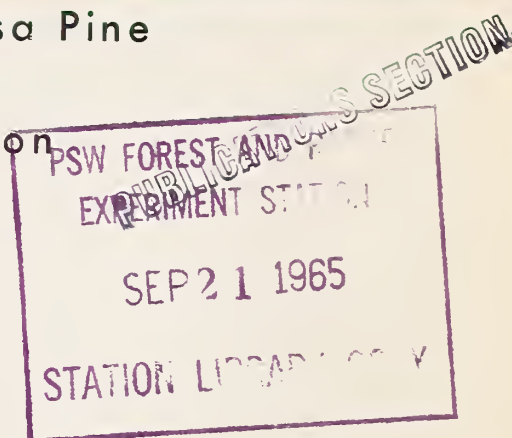
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ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Determining Growth of Ponderosa Pine

in Arizona by Stand Projection

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Growth of ponderosa pine in Arizona is normally determined by remeasuring permanently established plots. In many instances, however, it is desired to get growth rates without waiting. Growth rates can be determined from one sampling of a forest by applying the stand projection method described by Hasel.[2]

A permanent sampling system is established by locating strip cruise center lines and point samples, the suggested methods for developing stand tables required for stand projection. This system can then be converted to a permanent plot remeasurement method of growth determination. Mortality and ingrowth estimates will also become available with subsequent inventories.

How the Method Works

Hasel's stand projection method involves determining the gross change in numbers of

trees per acre in each 2-inch diameter class for a projection period. This method is similar to other stand projection techniques in assuming the change in a future period will equal that of a past period. The change in a 2-inch d.b.h. class is the difference between the numbers of trees growing into and out of that class during the projection period. If mortality data are available, gross change can be converted to net change.

The change in numbers of trees per acre for each 2-inch d.b.h. class is multiplied by average individual tree volume for that class. By adding the volumes for all classes, growth is determined.

The method requires the following information:

1. A stand table of growing stock by 2-inch d.b.h. classes.
2. Average annual rate of diameter growth by 2-inch d.b.h. classes.
3. Height measurements corresponding to 2-inch d.b.h. classes to make local volume tables.

All of the information needed to apply the method can be obtained from a single "cruise" of an area.

Stand Tables

It is suggested that point sampling be used to develop stand tables describing growing stock distribution in the large pole and saw-timber size classes. The first step in initiating a permanent sampling system is completed by permanently locating the points and marking the trees measured.

A strip cruise should be used to develop a stand table describing growing stock distribution of sapling and small pole size classes. Point sampling should not be used to measure the smaller size classes because of the clumped pattern of distribution of these classes in southwestern ponderosa pine. Point sampling is similar to fixed-plot sampling for a given 2-inch d.b.h. class, and a small area will be sampled compared to the total area of the population. Too large or too small numbers are often obtained when numbers of trees of a clumped distribution are tallied from small sample areas and expanded to an acre basis.[3]

Which of the 2-inch d.b.h. size classes should be sampled by a strip cruise will depend on the basal area factor selected for point sampling. The smaller the factor, the smaller the 2-inch d.b.h. classes that can be sampled by a strip cruise.

For efficiency, locate the point samples at regular intervals along the strip cruise center line, and carry out the strip cruise and point sampling simultaneously.

Diameter Growth

Increment borings are needed to determine average annual diameter growth. These borings must describe accurately diameter growth within each 2-inch d.b.h. class in the population sampled. The first tree tallied on the point samples can be bored to meet this objective. Trees in the smaller size classes can be selected in a similar way.

Height Measurements

Height measurements corresponding to 2-inch d.b.h. classes must be taken to make local volume tables. The trees selected for diameter growth information can be used for these measurements. As these trees will have been bored, height and age data will be available.

Sample Design

Systematic sampling with multiple random starts[4,5] can be used to measure the variability between lines of strip cruise and point samples. This system will allow for computing measurements of variation in addition to insuring a representative sample of an area.

While there are unknown errors in the stand projection method, sampling errors should meet predetermined limits of precision. This means sampling intensities for different levels of precision and probable error must be computed, which requires knowing how much variability exists in the stands in terms of the data necessary to apply Hasel's method.

Measurements of variability become available from a systematic sampling design with multiple random starts. The number of point samples, and the area to be sampled by a strip cruise, necessary to develop stand tables at given limits of precision can be computed. Also, the number of increment borings and height measurements needed in each 2-inch d.b.h. class can be found. An efficient sampling system can be designed from these data.

Computations

Hasel's method is similar to the stand projection method described by Meyer.[6] The

[3]Odum, E. P. *Fundamentals of ecology.* *546 pp., illus. Philadelphia-London: W. B. Saunders Co. 1959.*

[4]*Shiue, Cherng-Jiamm. Systematic sampling with multiple random starts. Forest Sci. 6: 42-50. 1960.*
[5]*Freese, F. Elementary forest sampling. U.S.Dept. Agr. Agr. Handb. 232, 91 pp. 1962.*
[6]*Meyer, H. A. Forest mensuration. 357 pp., illus. State College, Pa.: Penn's Valley Pub., Inc. 1953.*

Table 1.--Hasel's stand projection method

D.b.h. class	(1) Number trees per acre	(2) N_i	(3) Q_i	(4) Log Q_i	(5) b_i	(6) g_i	(7) $b_i g_i$	(8) Antilog $b_i g_i$	(9) r_i	(10) $N_i r_i$	(11) $(N_i r_i) - (N_{i+1} r_{i+1})$	(12) V_i	(13) G_i
2	612	798.20											
4	100	186.20	4.287	0.6322	0.3161	0.0913	0.0289	1.069	0.069	12.85	9.92	0.8	7.94
6	44.1	86.20	2.160	.3344	.1672	.0871	.0146	1.034	.034	2.93	1.67	2.3	3.84
8	16.8	42.10	2.048	.3113	.1556	.0833	.0130	1.030	.030	1.26	.75	4.8	3.60
10	9.48	25.30	1.664	.2212	.1106	.0798	.0088	1.020	.020	.51	.23	8.7	2.00
12	4.61	15.82	1.599	.2038	.1019	.0766	.0078	1.018	.018	.28	.13	14.2	1.85
14	2.24	11.21	1.411	.1495	.0748	.0736	.0055	1.013	.013	.15	.08	21.5	1.72
16	1.12	8.97	1.250	.0969	.0484	.0709	.0034	1.008	.008	.07	.03	30.5	.92
18	2.12	7.85	1.143	.0580	.0290	.0693	.0020	1.005	.005	.04	-.02	41.5	-.83
20	2.00	5.73	1.370	.1367	.0684	.0660	.0045	1.010	.010	.06	.01	54.5	.54
22	1.62	3.73	1.536	.1864	.0932	.0638	.0059	1.014	.014	.05	.01	67.6	.68
24	1.00	2.11	1.768	.2475	.1238	.0617	.0076	1.018	.018	.04	.02	84.5	1.69
26	.62	1.11	1.901	.2799	.1400	.0598	.0084	1.020	.020	.02	.01	100.	1.00
28	.37	.49	2.265	.3551	.1776	.0579	.0103	1.024	.024	.01	.01	121.	1.21
30	.12	.12	4.083	.6110	.3055	.0562	.0172	1.040	.040	.00	.00	138.	.00
Total													26.16

Step 1. Enter number of trees per acre by 2-inch d.b.h. classes in column 1.

Step 2. Compute cumulative total numbers of trees for each class, beginning with the largest 2-inch d.b.h. classes, and record in column 2 (N_i).

Step 3. Divide each total in column 2 (N_i) by the total in the next larger class, and record the quotients in column 3 (Q_i).

Step 4. Enter the logarithm of Q_i in column 4.

Step 5. Divide each logarithm of Q_i by 2 and record the quotients in column 5 (b_i).

Step 6. Enter average annual diameter growth (g_i) for each 2-inch d.b.h. class in column 6.

Step 7. Multiply each b_i in column 5 by the corresponding g_i in column 6, and record the products in column 7.

Step 8. Enter antilog of each product of b_i and g_i in column 8.

Step 9. Subtract 1 from each antilog in column 8 and enter in column 9. These r_i values are rates of ingrowth into each 2-inch d.b.h. class.

Step 10. Multiply the cumulative total numbers of trees for each 2-inch d.b.h. class (N_i) by the corresponding ingrowth rate (r_i) and record the products in column 10.

Step 11. Subtract outgrowth (ingrowth in next larger 2-inch d.b.h. class) from ingrowth for each 2-inch d.b.h. class ($N_i r_i$)-($N_{i+1} r_{i+1}$), and enter the gross change in the number of trees in each 2-inch d.b.h. class in column 11. If mortality and cutting records are available, adjust gross change as follows: (Gross change) - (Mortality) - (Cut) = net change in each 2-inch d.b.h. class.

Step 12. Enter average volume of a tree (v_i) in each 2-inch d.b.h. class in column 12. V_i is volume of entire stem in cubic feet.

Step 13. Multiply the gross change in the number of trees in each 2-inch d.b.h. class in column 11 by the corresponding average volume of a tree (V_i) in column 12, and record products in column 13 (G_i).

Step 14. Add column 13. Summation is growth per acre per year.

ratio of cumulative numbers of trees in adjacent size classes was used to calculate Q by Hasel in place of q = the ratio of numbers of trees in adjacent d.b.h. classes used by Meyer. The procedure followed in applying Hasel's stand projection method is outlined in table 1. Data collected on a 450-acre watershed on the Beaver Creek Watershed Evaluation project in Arizona[7] are used to illustrate the procedure.

[7] A 275,000-acre watershed on the Coconino National Forest in northern Arizona where costs and benefits of intensive multiple-use land management are being evaluated as a part of the Arizona Watershed Program.

Test of Method

Hasel's stand projection method was used to determine ponderosa pine growth rates (gross) on a 450-acre watershed on the Beaver Creek Watershed Evaluation project. The results of this test illustrate how the method can be applied in Arizona.

Systematic sampling with four strata and four random starts (fig. 1) was the design placed on the test watershed. Each sample unit consisted of point samples at 3-chain intervals and a strip cruise 1/4 chain wide.
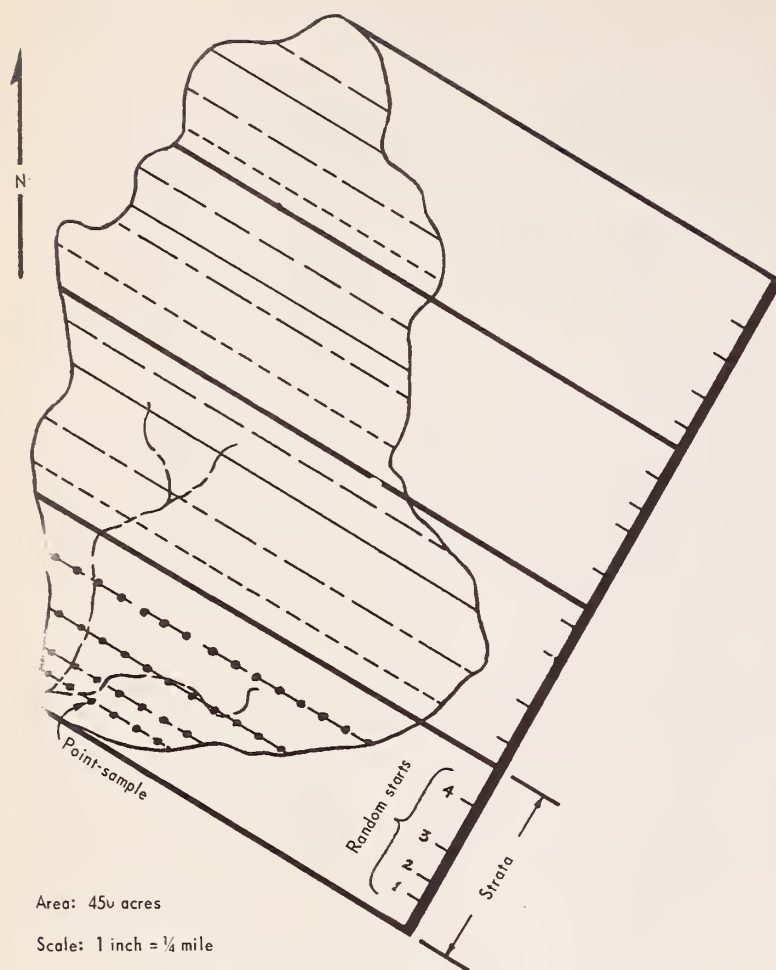
Figure 1.--Systematic sampling with four strata and four random starts.

Area: 45u acres

Scale: 1 inch = ¼ mile

Increment borings and height measurements were taken on the first tree tallied on the point samples. Point sampling with a basal area factor of 25 was used to develop stand tables for trees 8 inches d.b.h. and larger. Stand tables for trees less than 8 inches d.b.h. were constructed from the strip cruise.

Growth rates were determined for each sample unit, and an average was obtained for the watershed. The average growth rate was 34.5 ± 2.3 cubic feet [8] per acre per year. The coefficient of variation was 52 percent.

[8]*Myers, C. A. Volume, taper, and related tables for southwestern ponderosa pine. U. S. Forest Serv. Res. Paper RM-2, 24 pp., illus. Rocky Mountain Forest and Range Expt. Sta., Fort Collins, Colo. 1963.*

The number of point samples, using a basal area factor of 25, and the number of chains of strip cruise, 1/4 chain wide, needed to develop stand tables for different levels of precision for growth determination were determined from measurements of variability between sample units, as follows:

Level of precision	Chains of strip cruise	Number of point samples
P = 0.67:		
5 percent	2,279	540
10 percent	570	135
15 percent	254	60
20 percent	143	34
P = 0.95:		
10 percent	2,370	431
15 percent	1,054	193
20 percent	593	109

The average number of increment borings needed in each 2-inch d.b.h. class, based on 191 borings, was computed for different levels of precision:

Level of precision	P = 0.67	P = 0.95
5 percent	26	--
10 percent	7	34
15 percent	3	15
20 percent	2	9

The average number of height measurements needed in each 2-inch d.b.h. class, based on 187 measurements, was also calculated for different levels of precision:

Level of precision	P = 0.67	P = 0.95
5 percent	11	--
10 percent	3	14
15 percent	2	6
20 percent	1	4

Sampling intensities and number of increment borings and height measurements may be helpful in designing samples on areas similar to Beaver Creek.